Reflections on the Philosophy of
SIR ARTHUR EDDINGTON

BY

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WITH
AN INTRODUCTION BY
C. E. RAVEN

THE FIRST
ARTHUR STANLEY EDDINGTON
MEMORIAL LECTURE
4 November 1947

CAMBRIDGE
AT THE UNIVERSITY PRESS
1948

Printed in Great Britain at the University Press, Cambridge
(Brooke Crutchley, University Printer)
and published by the Cambridge University Press
(Cambridge, and Bentley House, London)
Agents for U.S.A., Canada, and India: Macmillan

THE ARTHUR STANLEY EDDINGTON MEMORIAL LECTURESHIP

This Lectureship was instituted in 1947 with the intention of providing a fitting memorial to Sir Arthur Eddington, O.M., Plumian Professor of Astronomy in the University of Cambridge from 1913 to 1946.

The lectures are to deal with some aspect of contemporary scientific thought considered in its bearing on the philosophy of religion or on ethics. It is hoped that they will thus help to maintain and further Eddington's concern for relating the scientific, the philosophical and the religious methods of seeking truth and will be a means of developing that insight into the unity underlying these different methods which was his characteristic aim.

Man's rapidly increasing control over natural forces holds out prospects of material achievements that are dazzling; but unless this increased control of material power can be matched by a great moral and spiritual advance, it threatens the catastrophic breakdown of human civilization. Consequently, the need was never so urgent as now for a synthesis of the kinds of understanding to be gained through the various ways—scientific, philosophical and religious—of seeking truth.

The Lectureship is managed by a Board of four Trustees appointed by The Royal Society, Trinity College, Cambridge and the Society of Friends.

H. DIAMOND
Secretary to the Trustees

45 ST BARNABAS ROAD
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Professor Ritchie's lecture was introduced by the Chairman, Rev. Prof. C. E. RAVEN, D.D., *Master of Christ's College and Vice-Chancellor of the University, in the following words:*

When Sir Arthur Eddington died, we realized not only that a great mathematician and physicist, a great Cambridge man, a great Christian and a great Friend had been taken from us, but that here was a man whose work was vital to the present situation, and that as such we could best commemorate his memory by the traditional means of inaugurating a lectureship dealing with some aspect of his own particular contribution to thought.

No one in recent times has been more successful in interpreting to ordinary folks the meaning of modern scientific discovery, particularly in relation to physics. He gave us an insight into the nature of the universe as the modern scientist conceived it, such as we have had from no other. Moreover, he insisted upon the significance of the change which that new knowledge involved for the whole sphere of human thought; and devoted himself, especially in the later years of his life, to the task of interpreting that change in terms of a philosophical system, trying to see the whole range

of man's experience in a coherent and ordered picture. How far his own philosophy was satisfying, how far he in any sense solved the questions which he propounded, is not for a mere historian to attempt to discuss. His philosophy has been severely criticized by many, some of them wise and some of them very much less than wise: but the verdict upon it cannot be expected yet.

We have in Professor Ritchie one who is admirably qualified to speak about Eddington's philosophy. Reading him we shall become wiser as to the significance—the permanent significance—of what Sir Arthur has done. But whether we conclude that Sir Arthur's work be permanent or impermanent, whatever the precise value of his constructive thinking, one thing is quite certain, that he was aiming, as many philosophers seem to us not to be aiming, at the things that really matter. He was 'on the target' all the time, because the task to which he set himself, the attempt to see reality steadily, and see it whole, to interpret man's religion and man's science in terms not only mutually intelligible, but mutually interdependent, remains, as I believe, the great task of our time if we are to see any stable order in events or make any consistent sense of experience.

It is a very great pleasure and privilege to introduce Professor Ritchie, a very great pleasure

because as a Cambridge man he is one of our own, coming back to us not for the first time, and because we love to have him among us; a very great privilege because better than almost any he is fitted to take up and expound to us the themes, the high themes, to which as scientist and as philosopher he also is dedicated. It is a special pleasure to introduce him as the first Arthur Stanley Eddington lecturer and to speak the prelude to his paper 'Reflections on the Philosophy of Sir Arthur Eddington'.

REFLECTIONS ON THE PHILOSOPHY OF SIR ARTHUR EDDINGTON

THE first task for anyone discussing Eddington's philosophy is to clear away certain misunderstandings that have cropped up. Eddington himself is not entirely free of blame for the misunderstandings. The very brilliance of his exposition and the felicity of his illustrations sometimes carried him further than he may originally have intended. He had, too, a somewhat mischievous sense of humour which delighted in making quite modest statements look like paradoxes. Miss Stebbing's criticism, so far as well directed, is essentially an attack on Eddington's loose and often misleading terminology. He did something to correct defective statements in his later book, *The Philosophy of Physical Science*, and I shall base my discussion on that. For the rest, Miss Stebbing's attack is mistaken, but her main mistake is one which I confess I shared till recently.

Eddington often speaks almost as though combining the 'idealism' of Berkeley and Hegel.

Sometimes he seems to say that the whole visible and tangible world consists solely of 'ideas in the mind', at others that theoretical knowledge is a self-contained autonomous system developing itself according to its own logical nature. His insistence that the realm of physical science is 'subjective' and that we encounter the 'objective' chiefly, if not only, in the realms of life, consciousness and spirit, could be taken in either way.* I propose to take it differently, following his explicit statement that his intentions and general outlook are those of Kant. Of course Kant was supposed by some contemporaries to be a Berkeleian, and Hegel undoubtedly thought him at least partly a Hegelian. Kant repudiated the first supposition and, had he been alive, would have repudiated the second.

It may help to clarify things if I start from Kant's starting point, namely that there are definite limits to scientific knowledge and that there is an extra-scientific realm with which we have acquaintance of a different kind and, if it is to be called knowledge, a different kind of knowledge. So far Eddington would agree pretty closely; probably in general outline, too, as to the extra-scientific realm, though Eddington's explicit statements do not go very far. One remark on this point may be

* *Philosophy of Physical Science*, p. 69.

made at once. For all the difference between eighteenth-century East Prussia and twentieth-century England, there is a strong resemblance between the religious faith of the Pietists in which Kant was nurtured and which influenced his thinking very strongly, and the faith of the Society of Friends, which influenced the thinking of Eddington. I shall return to this aspect of things later. In the meantime I shall deal at greater length with Eddington's philosophy of physical science, both because it was that he wrote about most and also because of the misunderstandings already mentioned.

Again, it is convenient to start from Kant, taking two of his points. The first is that sense experience and thought are inseparable in use within the scientific sphere, but are distinct in kind; as against both Leibniz and Hume and also many recent thinkers. Eddington probably never considered this question, and may have lapsed into taking sensation to be a kind of thinking or thinking a kind of sensation, but I wish to keep the distinction in mind throughout. The second point he grasped very well, the one expressed in the well-known phrase that 'reason has insight only into that which it produces after a plan of its own'. Kant said this as an afterthought and probably never worked it out thoroughly; indeed, in his day it was not so

easy to see its implications. At any rate, from the two statements together we can see that scientific knowledge is not only limited (as all agree) but in part also constituted (as many deny) by epistemic conditions; namely, the conditions under which experience is obtained and thought operates; the obtaining and operating being different aspects of one process. Kant assumed that three sciences were fundamental, each complete in general outline, and each in its own sphere universal. These were Aristotelian Logic, Euclidean Geometry, Newtonian Mechanics. Those aspects of each which were universal, the same everywhere and applying to everything, he held to be *a priori* in the sense that they express epistemic conditions, as just defined. To those who argue that if we wished we could obtain other experience and think otherwise, the answer is: 'Of course you can if you wish to deceive yourself, and as actually happens in dreams.'

I have introduced this term 'epistemic conditions' in order to avoid the confusion caused by the modern use of the terms *subjective* and *objective*, a confusion that goes back to the time of Kant, and that Eddington has done nothing at all to clear up. There was no difficulty about them until the older meanings became reversed in philosophic jargon. The original meanings are preserved in common speech; as when I say the *subject* or matter of my

lecture is so and so and my *object* or aim in lecturing is such and such. Nowadays *objective* tends to mean real, genuine, permanent, physical; and *subjective* to mean mental and otherwise whatever is supposed to be the opposite of objective. Thus, the aim or object of lecturing, being mental, is now called *subjective*, and if the subject of the lecture is physics that is called *objective*. This new usage springs from the recognition of what is in itself a valid, indeed a vital, point; that any kind of experience, thought, feeling, or awareness is a bipolar process. There is the pole which is the experienc*ing* and the other which is the experienc*ed*; they may reasonably be called subjective and objective. Though the two poles are distinct, they cannot be separated. The analogy of magnetic poles is useful here. If a bar of iron is magnetized, one end is always a North Pole, the other a South Pole. Cutting the bar in two does not separate them, it produces two short magnets each with its own North and South Poles. So, you cannot have subjective and objective poles of experience separated from one another. Articulate, reasoned knowledge does not deal with one pole separately, *qua* pole, but always with the general relations between them. However, in order to make knowledge common, public, or in any sense universal, it is necessary so to arrange things that the subjective

pole can be left out of the final account, extruded as irrelevant. This is needed not only to make the account common or public as between different persons but even for one person at different times and places. Common sense long ago found ways of abstracting from the subjective pole that were sufficient for ordinary practical purposes and for science up till the present century. They were, therefore, just taken for granted and ignored. Now they need to be taken into account.

If you walk out of Trinity Street into King's Parade you see Great St Mary's on your left and the Senate House on your right. The statement that St Mary's is to the left of the Senate House is perfectly correct, descriptive and unambiguous for anybody who is in that position and looking in that direction, but quite wrong for anybody elsewhere or looking in another direction, e.g. standing near the gate of King's. A correct account of the spatial relation of St Mary's and the Senate House in the language of right and left must include at least a third term in the spatial relation, namely the place from which the observation is made. This makes clear, what ordinary statements slur over, that the spatial relation of any two things cannot be found without at least three terms being involved, not those two terms only. The complete account cannot exclude the subjective pole as the

ordinary statement does. But the subjective pole so far as it is a region of space is just as physical as the objective. A camera can serve the purpose of the human eye, provided (an important proviso) there is also a human eye to look at the photographic plate afterwards, thereby turning the full statement into a four-term relation. The subjective pole is as physical as the objective, but it includes something mental also. The objective pole need not be mental, though it may be; but if so, that is not relevant to the science of physics, which is concerned with spatial and temporal relations in abstraction from those less determinate qualities we call mental.

Because the mental is left out of the physical account, it has been despised as a mere extra, epiphenomenal or even unreal. To see the error of this, it is enough to remember that the observer at the subjective pole is also agent or operator, and can make his presence felt if he wants to.

When we say '*A* is to the left of *B*', we have to add 'observed from *C*'. If, instead of left and right, we express the matter in terms of East and West, the third term in the spatial relation then becomes the Earth's axial rotation, and the observer can drop out as superfluous. That is how it has usually been conceived. But strictly the full statement is: 'Great St Mary's is East of the Senate House,

(*a*) relative to the Earth's axial rotation, (*b*) that rotation being observed from somewhere.' Anywhere on the Earth's surface will do equally well. A four-term relation masquerades as a two-term one because clause (*b*) is common to all statements of spatial relations on the Earth's surface and taken for granted, while clause (*a*) is implied in the relation 'East' (whether in modern terms of the Earth's axis or ancient ones of the rising and setting of the Sun) and also taken for granted. Thus, the epistemic terms drop out. Simple omission of these terms suffices for purely provincial dealings with terrestrial objects by terrestrial observers, but is useless for cosmic purposes. The first step in restatement of the epistemic conditions was taken with the development of the theory of the spherical Earth; the second with the Copernican theory, on a scale sufficient for the Solar System; the third with Einstein's Theory of Relativity, beginning a truly cosmic outlook. This is an outlook which requires to be constructed on the basis of observation from within, not outside; the admission that no observer has a position of greater privilege than any other observer elsewhere, and that all observations must be expressed in a common language.

For common sense and for the early stages of theory, including the Newtonian, it is easy to

frame all statements so as to be able to forget the epistemic part because it asserts a constant, universal condition and says nothing about any differential features distinguishing one set of observations from another. It is the differential features we are interested in, because they tell us something we did not know beforehand; they are empirical in that sense. Nevertheless, the final theoretical formulation aimed at for all physical laws is in terms of what is constant and universal; of the invariant. Traditionally, invariance has been taken as belonging solely to the objective pole of the epistemic relation. Eddington contends that invariance belongs to the epistemic relation itself and *to nothing else*; that is to say, without the epistemic to constitute or produce invariance there would be mere variability without rule or order or anything to speak about in general terms; facts, perhaps, but only chance facts. It may be going too far to claim that epistemic conditions *constitute* invariance because we can never scrutinize anything without them; we can never cut off one pole and examine it by itself. Wherever there are epistemic conditions there is that which is just given also. But certainly without epistemic relations there would be no invariance such as we find.

The point is prettily illustrated by Eddington's story of the fisherman who fishes with a net of

2 in. mesh and therefore concludes that all fish are more than 2 in. long. If the fisherman asserts that all *captured* fish are over 2 in. long his generalization is quite correct, but it is one about the net and the fish together; about the epistemic conditions, for the net is his instrument of knowledge. Eddington does not play quite fair in his use of the illustration and in his way of using 'subjective' and 'objective'. The fisherman's generalization is as 'objective' as anything can be and at the same time as 'subjective'. It is both because it concerns epistemic conditions. If the fisherman, on the basis of operations with the net, makes assertions about fish apart from the net, about fish in the sea, or as Kant would say fish-in-themselves, then he is simply wrong. Eddington calls the fisherman an icthyologist which suggests one who is interested in fish-in-themselves, whereas he is obviously a commercial fisherman who is not interested in fish less than 2 in. long because they would not be marketable even if they existed. The theoretical physicist is, in this respect, very like the fisherman. He deals only in marketable products, things which are under control. The laws of physics all imply, though they do not state, this aspect of control and it is part of the epistemic situation in physical science.

To explain my meaning I had better make a fresh start; and start with mathematics. Nobody

need be alarmed. I am going no further than simple arithmetic and the like, because my mathematical knowledge does not stretch much further, and also because it is at the very beginning that all the important questions crop up; the rest is routine. Arithmetic may be taken to be the free, arbitrary creation of the mind, and might be supposed, therefore, to have no relation to the physical or any other world. The mind does, indeed, create it freely in initiating it. Once initiated, the mind is thereafter bound to the relevant conditions of the physical world. This is not to deny that the principles of arithmetic can be deduced from principles that are purely logical, but to assert that the logical principles themselves contain an empirical element. For that reason arithmetic is, in its own way, as empirical as any part of physical science. Though a very abstract part, it is truly a part of physical science, not an alien intruder.

Let us suppose we are creating arithmetic for the first time, deliberately starting from something more general. We begin, then, by saying: 'Let there be symbols which can be manipulated in accordance with rules, hereinafter to be laid down.' The word manipulate is to be understood literally. Symbols are material objects, handled by physical methods and just as objective as any other objects. If the Universe consisted entirely of treacle of

uniform texture there would be no symbols, no rules, no manipulation, no manipulator; in short, nothing but treacle. The Universe is not like that, but contains recognizable and fairly permanent objects which can be used as symbols and others to which symbols can refer; labels and things to which the labels can be tied. That is the primary, basic empirical fact required for language and logic as well as mathematics. Given that fact, we can then devise our rules. I shall not expound them systematically or precisely but give some sample rules required by certain sorts of algebra; six will suffice. Our symbols are recognizable, distinct, self-identical; no one is equivalent to any other unless specifically found and stated to be so. We need symbols to stand for something, A, B, etc., one to stand for nothing, 0, and operational symbols, $+$, $=$, $\neq$. Then our rules are: (1) $A=A$, $B=B$, $0=0$. (2) In general $A \neq B \neq 0$; unless (3) for special reasons $A=B$, or $A=0$. But (4) either $A=B$, or $A \neq B$, not both. Then comes (5) a Rule of Addition $A+B \neq A$ or B unless A or $B=0$; (6) the Rule of Commutation, $A+B=B+A$. These rules are arbitrary to the extent that we choose whether to put them in or not. But from whatever is put in and left out consequences follow, follow of necessity, and are no longer matter for choice. The consequences, too, have to be dis-

covered in a way that can hardly be called anything but empirical. We can choose to drop the last, the commutative rule, but in that case we shall not be able to develop ordinary arithmetic; we shall have a special kind of algebra instead. And why not? With some things it makes no difference in which order you take them, with others it does make a difference. The shopkeeper does not mind whether I pay a bill of 1*s*. 1*d*. by paying a penny first and then a shilling or the other way about or in many other ways, provided the sum is the same. When I leave the shop I can open the door first and then walk out; but I cannot walk out first and then open the door. Arithmetic applies directly to paying bills, but not similarly to walking through doors. *A*'s and *B*'s are more accommodating; we can take them either way according to taste. But having taken them one way we are then bound by our self-imposed rules to take the consequences too.

Suppose we want arithmetic, then we add to the rules already stated a few more, like definitions of zero and unity, a rule for proceeding from a number to its next-door neighbour and then go ahead. Instead of vague *A*'s and *B*'s which may be anything, we obtain 1, 2, 3, 4, 5, etc. which are precisely certain sorts of things and not any others. This number series, once it is created, has its own

properties and these have to be discovered. In their way they are as objective as anything under the Sun and they are also in their way arbitrary creations. *Arbitrium* means choice, judgement, decision, which may be merely fanciful, hence the common abusive sense of arbitrary, but equally may be reasonable and factual. If you like, you can call the choice 'subjective'. The conditions governing the nature of numbers are epistemic, but equally the conditions are part of the physical world.

If anybody doubts this about numbers, let him consider the question, 'How many prime numbers are there between 100,000 and 1,000,000?' I have deliberately refrained from taking steps to find the answer to this question, in order to avoid any risk of producing it. The answer may be none, or 5, or 50, or more; but I am quite certain and everybody else is certain that there is an answer, a perfectly definite one, to be discovered. It makes no difference whether it is now known to anybody or not. It can be obtained by the laborious and evidently empirical process of taking each odd number in turn, 100,001, 100,003, and so on, and factorizing it until we come to one with no factors, writing that one down in red ink and then going on to the next. This process consists in handling and examining things. True, they are only coloured

marks on paper and they are used as symbols, but they are things and are physical for all that. If I were clever enough or the problem simpler I might be able to do the work 'in my head' without writing anything down. I should still be using symbols, images of some sort. My images are very inaccessible because all material processes related to them are inside my body and not open to inspection by any other person, as are ink marks on paper. But still images are things of some sort having some sort of relation to the rest of the physical world.

There is another method which sounds less empirical, if a general formula is known which gives the distribution of prime numbers among the natural numbers and if a general proof for the formula has been found. But who would accept a formula or its proof as valid until it had been tried out successfully in a good many cases for small and fairly large numbers? Moreover, it has to be applied to the special case. The use of a general formula lightens the labour of empirical investigation by introducing the hypothetical deductive method which is so much more powerful a weapon in all the sciences than plain induction; but it does not abolish it.

Mathematicians can and do invent non-numerical algebras which are alleged to have no

relation to empirical fact. As I am not a mathematician it is difficult for me to counter the allegation; I can only voice a suspicion and point to an undoubted empirical fact. I suspect that when mathematicians make these excursions they go ahead until they find something very queer happening to their symbolic patterns that offends their sense of propriety. If that happens, they quietly drop what they have written in the waste-paper basket and say nothing about it. What they keep and show to their friends and ultimately publish is that part of their efforts which does not get too fantastic, bears therefore some relation to empirical facts and submits to be checked by them. That is my suspicion. Now for the fact already mentioned; that symbols, however ingeniously devised and manipulated, are still material objects and limited by the character of the world we inhabit.

Mathematics is one instance of the mechanical game of pushing things about; highly generalized, conventionalized, abstract, symbolic pushing, it is true. Operational signs are derived by analogy from simple spatial relations. To begin with, the plus sign means 'put together', the minus sign 'take away'. To say $A=B$ means that it makes no difference when A is put in the place of B. The special mathematical character depends on the way

in which one operational sign can stand for sets of operations of any number and complexity and one term can stand for sets of terms of any number and complexity. What is more, analogy can be stretched as far as you like.

Let me introduce the higher mathematics; hitherto I have only discussed the elements. A mathematician says to a child: 'Suppose there are five apples on the table, take away two, how many are left?' And then: 'Take away three, how many are left?' In each case the child answers correctly. Then he says: 'Suppose two apples on the table, take away three, how many are left?' And the child says: 'It can't be done.' The mathematician then says: 'Ah, you are too timid, my lad. Let us suppose it can be done, so that, just as we can put on any number of apples we like, we can take off any number we like. Let us call those put on, positive apples, and those taken off, negative apples; and there you are. The answer to my question is, one negative apple or minus one.' At any stage when the plain man is inclined to stop and say: 'It can't be done', like the child, the mathematician just goes ahead saying: 'Suppose it is done, what then?' It seems a disreputable procedure, but it must be quite respectable really because the first step, the only one which counts, is taken by bankers; only they do not talk about

positive and negative money but Credit and Debit; that makes it sound better.

My first main point then is that the pure mathematician is not so very pure after all. My second, which brings me back to Eddington, is that the applied mathematician is far purer than is usually supposed, however empirical he may be. Before going on to the second point there is a comment to be made.

This is something that Whitehead has put very well*; Eddington also, but not so simply. As Whitehead says, nothing can be clearer or more certain than that $2 \times 3 = 6$. But the clarity and certainty extend only to the entirely universal relation between the terms and not to the terms themselves. They may be all sorts of things. As soon as anybody starts inquiring what numbers really are he gets into difficulties. The answers are very complicated and may be neither clear nor certain. But any obscurity and uncertainty surrounding the terms in no way impairs the clarity and certainty of the relations. This is true of all kinds of scientific knowledge and is the reason why mathematics can be used and why it is such a powerful tool. Again, clarity and certainty depend upon what has been put into the account by the epistemic conditions, by the decision to play a game

* *Essays in Science and Philosophy* (1947), p. 211.

of a certain kind. Eddington rather obscures the point by emphasizing the mathematics of groups, which only elaborates something equally true of the multiplication table.*

The analogy of games is intended quite seriously. The rules of a game spring from a free choice of the kind of competitive activity we wish to pursue; but to produce a successful game the choice must be exercised within the limits set by the nature of the physical world. People could decide to play golf with a football or football with a golf-ball, but they would soon give it up. You can change a rule and if you do you get a different game; e.g. the origin of Rugby Football. There is an element of pure convention in a game (e.g. the exact limits of size and weight specified for golf-balls), but it is a small element operating within narrow limits. For the most part rules, though freely prescribed, are designed to make the game as good as possible and that means that they conform to the character of the physical world as discovered in the course of playing the game; characters not to be discovered without playing the game. What I am leading up to is simply this. Physical science is the consequence of deciding to play the game of mechanics, of pushing things about and seeing what happens and of doing it in every possible way

* *New Pathways in Science*, p. 255.

in actual fact, not merely in the highly abstract, hypothetical way of the mathematician. Because the mathematician plays a completely generalized, hypothetical, symbolic kind of mechanics, he therefore has greater scope, but he never finds out anything about anything in particular; the physicist actually pushes things about and uses whichever formulations of the mathematician suit any special case. The physicist's pushings are aimed at controlling things, and do tell us about certain things as distinguished from other things.

The first stage in the mechanical game proper is Euclidean Geometry. The Greeks called this science Geometry, not out of ignorance or inadvertence, but meaning just what they said. The first three postulates explicitly stated by Euclid and others implicit in his procedure constitute the decision to play the game of mensuration; to use a straight edge, dividers and compass to construct figures, to follow out the consequences and generalize them as far as possible. Euclid operates half-way between the purer forms of mathematics where no physical movement is prescribed and the full mechanical process. He only moves his tools; the movements are not included in the theory which treats everything as though all spatial relations were permanent. The next step was not taken fully and quite explicitly till the time of

Galileo. Galilean mechanics includes the motions of bodies, their change in spatial relations, but no other change. To Plato and Aristotle a science of mere locomotion that excluded aim or purpose would appear trivial. Indeed, the attempts of their day, including the theories of Democritus, were no more than playing with words, for the exponents never *did* anything. Aristotle's physical rules produce a different game, possibly a more interesting one, but one too difficult for ordinary players. The mechanical game has easy rules, is easy to play and not so trivial as it looked in early days.

Newton's Laws of Motion state in general terms what is uniform or universal about the consequences of imposing these epistemic conditions on things, i.e. of pushing them about and measuring them. The consequences had to be discovered empirically in the first instance and not by any process of deductive reasoning from first principles. In the same way it had to be discovered empirically in the first instance that 16 is the square of a square and 17 a prime number. After the main empirical discoveries have been made so as to give the outlines of the field of study it may then be possible to show that empirically discovered properties follow logically from the nature of the game being played. It does not follow that they

could have been predicted beforehand, or that any matter of fact can be predicted except from other facts. It is sometimes said nowadays that Newton's laws are definitions (of Inertia, Mass, Force) and are true by definition, or that they are pure conventions, or imposed *a priori*. All these are rather misleading ways of referring to their epistemic character; misleading, if they suggest that the laws are arbitrary in a vicious sense. The *arbitrium* of the mind in this case is part and parcel of the world on which the laws are imposed. They spring from successful operation initiated by the mind in that world. The arbitrary that fails to operate is vicious, not the arbitrary that succeeds.

If anybody says this is Pragmatism, the reply is that the method of science is pragmatic and the only error of the upholders of the '-ism' is to turn negative into positive. Failure, in the sense of failure to control, is the prime test of falsehood; but success in control is not the sole test of truth, nor does it constitute the nature of truth.

The problems of the philosophy of physical science in Kant's day were not so difficult because the realm of eighteenth-century physics lay within limits where common-sense ways of dealing with the epistemic situation seemed sufficient. The physical universe was still the man-size world with only insignificant extensions in scale, above and

below; the realms of the very small and the very large were unexplored. The instruments of measurement were still in all essentials Euclid's straight-edge, dividers, and compass, slightly extended in range by use of optical instruments. The pendulum, balance, barometer and thermometer had introduced new post-Euclidian concepts but no new principles. Most important of all, the laws governing the use of instruments, capable of being apprehended in the very process of use itself, were the same laws that governed the motions of all bodies so far investigated; including, to everybody's amazement, the 'heavenly bodies' which cannot actually be pushed about at all. This was, in brief, the result of Newton's great synthesis.

The nineteenth century saw the first penetration of the minute realm of the molecular, or corpuscular within that of the molar or corporeal (the modern term or Newton's will do equally well). The attack on the realm of the very large, outside the Solar System, also began. Thanks to the systematization of physical theory by Newton and the French theorists of the eighteenth century, the nineteenth-century physicists rested in their dogmatic slumbers and their snoring drowned the small voice of criticism. With the opening years of the twentieth century new discoveries and new problems came with a rush and the sleepers began

to wake up. Historically, the first challenge came from the realm of the very large; from discrepancies in traditional formulations that led to the Theory of Relativity. It might have come earlier from the realm of the very small. It should have been plain enough long ago that if the bodies we handle, molar bodies, are aggregates of very large numbers of minute entities, then many, if not all, molar properties, must be statistical, and based far more on the relations of large numbers than on the properties of the small units individually. The Kinetic Theory of Gases really makes this point quite clear. It follows that some at least, if not all, the laws of the properties and relations of the units singly or in small numbers are bound to be entirely different from the laws of molar bodies. The American thinker, C. S. Peirce, seems to have grasped the point in the 1890's and Poincaré had some inkling too, but nobody else took much notice.

This state of affairs produces an awkward problem. Most people assume, with Eddington, that in some way the primary laws of physics must be those of the smallest units, electrons, protons, neutrons, photons, etc.; and that the classical Newtonian laws should be derived by logical deduction from them. But the behaviour of the smallest units is never 'observed' in any proper

sense of the word 'observed'. It is inferred from genuine observations belonging to the Newtonian realm, on the molar scale, by means of specially designed instruments, like the Wilson Cloud Chamber. The design and operation of the instrument depends upon assuming that its behaviour is strictly Newtonian. Epistemically, Newtonian laws are primary and those of the very smallest entities of the sub-molecular realm are derived. That Newtonian laws are statistical does not in itself lower their status. An aggregate of parts, as such, has the properties it has in its own right, and has no others. That is so, even if they are mainly numerical properties depending on the relations of large numbers. They have to be discovered like any other properties.

There are two common sources of confusion here: one about perception and observation, the other following from it.

As to the first, the physicist in designing, making, calibrating, using and adjusting his apparatus adopts the perceptual standpoint of naïve realism. His instruments are taken to be in reality as they appear to be in seeing and handling. Steel and brass are hard, rigid and heavy; glass is hard, rigid, heavy and also transparent, and so on. When, however, he is theorizing about things he drops this standpoint and assumes that his theoretical

entities alone are real; that hardness, rigidity, heaviness and transparence are mere appearances and remote effects produced by theoretical entities in virtue of their own quite different properties. When he thinks about the perceptual processes of other people he adopts still another standpoint or mixture of standpoints. What other people experience is a copy of the real properties of things, which copy is something inside their minds, whereas the real thing is outside their minds. Mixed with this is another version of the causal theory according to which the other man's perception is some special kind of process going on inside his brain caused by things outside his brain. The thing he is said to see is not of course inside his brain nor can the process inside his brain be hard, rigid or heavy. The hardness, rigidity and heaviness therefore, which for the percipient himself is real, is an illusion for everybody else.

Commonly we all tend to get into this muddle; which is not only a muddle but immoral, because it implies that our own perceptions are superior to those of other people. The simple and honest, but difficult, thing to do is to try to apply as much naïve realism as possible all round, to refuse to be pushed out of it by plausible theorizing. In particular, we should for the time being set aside illusory experience as irrelevant, for nobody needs to be

illuded if he is careful enough. In that case the objects we perceive are *prima facie* all real objects, they occupy physical space and are somehow public and common to all observers. But what about electrons, protons, etc., are they unreal? By no means, but their reality is not the perceptual reality of what is directly observed, it is the theoretical reality of what is inferred. It follows that not only are they not themselves observed, they are not imaginable. We may be pardoned if we imagine an electron to be like a small bullet, provided we realize this is myth, not to be taken too seriously. Eddington's famous comparison of the common-sense chair that is visible and solid and can be sat on, and the physicist's chair that is mostly empty space thinly occupied by whirling electrons, may pass muster as a joke, but is not one of his best jokes. It depends on imagining in a way that makes imagination obscurantist.

Eddington's decision that the laws relating the ultimate units are primary is probably premature, as I think his own argument shows. For he has indicated how a decision should be sought, in what he says about analysis.* He points out, as Whitehead has done too, that there is no such thing as an independently existing individual. True, everything is what it is and not something else; but is

* *Philosophy of Physical Science*, pp. 118 seq.

what it is in an environment, without which it would not be anything in particular or even exist at all. From this it follows that the analysis of a whole into parts, to be done correctly, must always be a consideration of the parts as related to the whole, and not of the parts as though unrelated. In certain easy cases, as a rough approximation and particularly at the scale of man-sized objects, the relation can be neglected for certain purposes; but not in general and certainly not in what professes to be a final, complete or precise account.

From this principle springs Eddington's notion of the Cosmic Number, the number of ultimate particles in the whole material universe, by which the diameter of the whole system of Galactic systems and character of the electron and proton reciprocally determine one another. Naturally, I am not competent to discuss the calculations which Eddington develops in his posthumous work, *Fundamental Theory*. I can only say that on a superficial view some of his assumptions look a bit high-handed. Empirical premisses may have crept in unacknowledged and there may well be other technical flaws in the very complicated argument; flaws which it is the business of the mathematicians to detect if they can. Let us suppose that his speculations are overbold and that the work will have to be done over again and differently.

Yet, if it is true that the character of everything depends on its relations to other things, and modern theories of space and time hardly permit of any other assumption; if that is true, then there must be some universal relation capable of mathematical expression between the parts whatever they are, out of which things are constructed, and the whole lot of things taken together. At the present day attempts to state the relation are bound to be highly speculative, though there is more to go upon than in the days of Pythagoras. But from Pythagoras to Eddington such speculations are proper to be made and indeed necessary. The refusal to make them implies that radical kind of scepticism according to which there is no cosmos at all but everything is just higgledy-piggledy. This is a view often asserted, without those who assert it realizing its self-stultifying implications.

On one point at least Eddington does seem to have greatly oversimplified his problem. He considers only the relation between the smallest units and the whole cosmos. But, remember, we are concerned with an epistemic relation. Can it exclude consideration of the man-size world too? Surely the relation is threefold—Ultimate Units—Molar Bodies—Cosmos. Molar bodies are aggregates, many of their properties are statistical, but they are not all merely random aggregates, and

they possess the characters they have because of their mean position between the smallest and the largest. Sometimes the scale of this mean position is very definitely fixed. The human body is (roughly) from 1 to 2 m. long. No body more than twice 2 m. or less than half 1 m. could possibly be human. Size is no accident and has its proper inherent relation to the size of the electron, certainly (the body has to contain a sufficient number but not too many); and to the size of the whole physical universe, possibly. The man-size world should not be dismissed as an irrelevant accident of no interest to the theorist.

There are three sets of laws: those of the ultimate units—Quantum Theory; those of the man-size world—Newtonian Laws; those of the whole Cosmos as suggested by the various speculative efforts based on the Theory of Relativity. Which of them is primary? The answer would appear to be that no laws of one of the three realms taken simply can possibly be primary but only such as include the relation of the three realms together. Of course, if the universe is a chance aggregation, this kind of synthesis is not possible. All these speculations may be vain; for all that they will continue to be made.

I must now turn to the last question, the relation of the realm of physical science to what lies outside

it. Eddington said little about this except in his Swarthmore Lecture—*Science and the Unseen World*. Here he makes the three necessary points; that this is the realm of encounter between persons; out of this encounter springs the notion of moral obligation, of 'ought'; and these are not of much avail without the specific awareness of the presence of God, the infinite Person from whom finite persons derive their being. Eddington, in this lecture, was speaking as a member of the Society of Friends to Friends and there was no risk of their misunderstanding him; but to a secular-minded audience his incautious use of the word 'mystical' for this last point might easily cause misunderstanding; for many the word 'mystical' suggests only 'mystification' and that means hocus-pocus.

It is worth noticing two other peculiarities of Eddington's treatment. He makes the transition from science to religion very shortly and easily; at the same time he is very hesitating about making any transition at all. The cause of the hesitation is evidently that many scientific thinkers now suppose that the realm of science (generally conceived as just physical science) is self-sufficient and there is nothing outside it. They are either Positivists, who are self-contradictory but otherwise innocuous; or else of the school who would turn science into politics because they desire to change

the world not to understand it, beyond the bare minimum they suppose will suffice for their purpose. They think in terms of power, see physical science as the supreme instrument of power and see no limits to its efficacy. Their attitude is the modern equivalent of the old Black Magic, but more dangerous, for Black Magic was based on totally bogus information, whereas these people have not yet corrupted science.

It is a relief to turn from this kind of attitude to those who, like Eddington, value science as a way of understanding the world first of all; who take the contemplative or, perhaps one might say, aesthetic attitude to knowledge, like Pythagoras and Plato. For this attitude the transition from science to religion is short and easy; it is a change-over in the object and kind of contemplation but always contemplation for the sake of understanding. The difficulty on this view is to see why the realm of physics is worth contemplating. Indeed, Newton thought it somewhat trivial. The facts of physics are not themselves intrinsically interesting. The character of a physical entity, for physical theory, is exhausted in its general spatio-temporal relations, so that it suffers the defect that Whitehead calls 'vacuous actuality'. That its character is a product of epistemic conditions also, does not make it any more interesting. The density

of mercury is 13·56 at 15° C.; that is a fact. Nobody can get excited about it taken by itself. But if seen as one among many facts all falling into order within the scheme of the theory of atomic structure that fact enhances the artistic perfection of the scheme. Theory is a work of art and as such intrinsically interesting to contemplate. It differs from works more usually called artistic so far as it can never be mere fiction, and indeed fiction is to be eliminated from it as far as possible. This is because it conforms to a double standard, fidelity to fact as well as intrinsic perfection of form. It makes no difference whether there ever was a Prince of Denmark called Hamlet. It makes a great deal of difference whether electrons are as specified or not.

In a widely quoted phrase Eddington identified the realm of physics with that of the metrical. The identification might pass muster as a rough generalization and with some qualification. Otherwise it is misleading. It is true that measurement is the most powerful of all scientific tools because it gives precision of statement and makes available all the resources of mathematics. Nevertheless, measurement is not the only tool and it cannot be used except on the basis of previous non-metrical notions and operations, which are qualitative not quantitative. But these humble beginnings are generally forgotten. What seems to be most

important and most characteristic of physics is that it is concerned entirely with spatial and temporal relations of things taken in a certain way; above all, taken abstractly and symbolically. Eddington put the matter very well when he said that the world of physics is a shadow world of symbols; very well, provided we take the term 'shadow' strictly.* Shadows are quite genuine constituents of the physical world. They can provide definite though limited information about the things of which they are shadows. The shadow on the sundial gives the time of day with an error of only a minute or two when the necessary correction is made for the difference between solar and clock time; it also gives the Sun's altitude with fair accuracy. This relationship is a work of art of a modest kind. More cannot be required of a shadow. Shadows are thought of as unreal because thought of as deceptive; but only the fool, who mistakes a shadow for something else which it is not, is deceived by it. The shadow on the sundial derives its character from the Sun, the gnomon and the dial, but just because it is derivative it symbolizes their relations. The world of physics possesses many merits rightly ascribed to it but it is derivative and there are other worlds left unexplored by the methods of physics—the worlds of life, mind and spirit.

* *Science and the Unseen World*, p. 45.

Eddington in *Science and the Unseen World* misses out the useful connecting link, life; and I shall take the liberty of putting it in. The simplest way of approaching the subject is through the notion of Time. Physical theory deals with temporal process in terms of *before* and *after*, and has strictly no place for the *past*, *present* and *future* that enter into living experience. If these notions are applied to physics, then physics is seen to be dealing with the past. All facts are past facts. The future can be predicted if taken as though it were past, finished and complete. A study of the Nautical Almanac or similar works shows this; it does not distinguish past dates from future dates. The genuine present and future are incomplete; they are in the making, and life consists of the making. The poet said: 'I will arise and go now, And go to Innisfree.' Luckily, he was an Irish poet and did not use the ambiguous word 'shall'. Had he spoken of the past he would have said: 'I arose and went then....' There is no room for 'will' in the past that is complete and done with, only to be described in terms of necessity or chance. The present and future can be described also in terms of 'will' and choice.

Although the living is derived from the lifeless material world and dependent on it, it is not purely derivative, like the shadow; it is also initiatory.

This does not mean that the living are in some way exempt from the conditions that govern the material; on the contrary, they submit to further and more special conditions. In virtue of all this, the living possess characters of their own—their 'objectivity'.

Whereas the order of the physical world is a subordinate order and the observer is to some extent justified as representing himself as outside and independent of it, the orders of the living and even more of the conscious and spiritual are co-ordinate or superordinate; they have to be accepted on their own terms. This is the objective side of that reciprocal relation of which choice, will and initiative are the subjective. Subjective and objective poles play a different part at the level where objects are themselves subjects in their own right. It is the encounter between persons which generates moral obligation and introduces—to use the phrase of Leibniz and Kant—the realm of ends, relative to which everything else belongs to the realm of means.

I have tried to bring out three points. First, by circumventing certain confusions about subjective and objective, to restate the essentially Kantian notions that are the basis of Eddington's general approach to the theory of physical science. By means of these notions I believe we can preserve

what is valid in both the realist and idealist traditions, while avoiding their extremes. Truth is true because it conforms to reality, but knowledge is not passive recipience and its conformity to reality is not to be discovered by inspection from without, since there is no 'without' to inspect from. The only inspection we can make is from within; from within the limits imposed by the conditions of thought and experience. Thought does, in part, make its own objects; that is its spontaneity. Once made, they have their own intrinsic character which has to be discovered. Though we operate within limits, that does not prevent our ascertaining that they are limits, nor does it prevent our seeing that the physical way of approach is one way only, whose special virtues come from the very fact that it concentrates on certain aspects and leaves out others. That is the second point. I only touched on those other aspects, but I also considered a third point, Eddington's speculations about the Cosmic Number. It is with this that I should like to conclude, for it seems that Eddington himself considered it his most important piece of work, while many have been rather contemptuous of it. I am handicapped by the technical difficulties of the subject and my own incompetence. I can do no more than suggest that if you wish for cosmological theory here is an example

of how to do it; *an* example, not necessarily the perfect example or even the only one, as there is also Professor A. E. Milne's cosmology. Whether you wish it or not, speculations of this kind cannot be avoided if there is to be synoptic physical theory, and that means if there is to be respectable theory at all, not just scraps. This follows at once from Eddington's view of analysis. In the early stages, as a means to rough approximations, it was useful to assume that a part is what it is independently of its relation to the whole to which it belongs. Now it is an error, perhaps a fatal one. If Eddington had done no more than draw our attention to this, he would deserve our commendation.